Discovery of strong CIV absorption in the highest redshift quasar[⋆]

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Abstract We report the near-IR detection of a prominent CIV absorption in the rest-frame UV spectrum of the most distant known QSO, SDSS J104433.04−012502.2, at $z = 5.80$. This QSO was recently observed with XMM-Newton and it was found to be notably X-ray weak. The equivalent width of the CIV absorption feature (~ 10Å) strongly supports the idea that the X-ray faintness of this QSO is due to heavy absorption by gas with a column density $N_H > 10^{24}$cm^{-2}. The shape of the CIV feature suggests that this is a Broad Absorption Line QSO. Although absorbed by a huge column of gas, the observed continuum in the 0.9–2.4μm range ($\sim$1300–3500 Å rest frame) exactly matches the template of unabsorbed QSOs without invoking any reddening ($E_{B-V} < 0.08$ mag), indicating that dust in the absorbing gas is either absent or composed of large grains.

1. Introduction

Recent studies have found a significant population of QSOs whose soft X-ray emission is much weaker, with respect to the optical-UV emission, compared to what observed in "classical" QSOs (Elvis 1992, Laor et al. 1997, Yuan et al. 1998, Risaliti et al. 2001). In this class of objects the X-ray emission is more than 10–30 times fainter than expected from the optically selected population of QSOs. Although some authors have ascribed the X-ray faintness to an intrinsically different spectral energy distribution (SED), more recently evidence was found that absorption by gas along our line of sight might be responsible for the observed properties of these objects. Indeed, Brandt et al. (2000) identified a correlation between the presence of deep resonant UV absorption features (especially CIV) and X-ray weakness. In particular, many of the X-ray weak QSOs result to be Broad Absorption Line (BAL) QSOs (i.e. quasars with prominent absorption features blueshifted with respect to the resonant UV lines and ascribed to gas outflowing with velocities from from

~ 5000 km s^{-1} up to more than 30000 km s^{-1}). Vice versa, most BAL QSOs appear to be X-ray weak AGNs. Hard X-ray studies have shown that the X-ray faintness of these objects extends to the 2–10 keV band, and in some cases evidence for a photoelectric cutoff due to absorbing gas with $N_H \sim 10^{22} - 10^{23}$cm^{-2} was found, thus supporting the absorption scenario (Gallagher et al. 1999, 2001). Risaliti et al. (2001) have found, among a grism selected sample of QSOs, that X-ray weak QSOs tend to have redder colors, which is ascribed to dust reddening, again supporting the absorption scenario.

Most of the studies mentioned above (except for Risaliti et al. 2001) deal with QSOs at moderate redshift ($z < 1$). Recently, the enhanced sensitivity of the X-ray XMM-Newton telescope enabled to study the X-ray emission of the most distant QSOs. In particular, Brandt et al. (2001a) used XMM to observe the recently discovered QSO SDSSp J104433.04−012502.2 at $z = 5.8$ (Fan et al. 2000) and achieved a detection in the 0.5–2 keV band. When compared to the (rest frame) UV emission, this high redshift QSO is X-ray weak with respect to the optically selected QSOs, similarly to the lower redshift X-ray weak QSOs. The nature of the X-ray weakness of this QSO is not clear and, in analogy with the local X-ray weak QSOs, it could be ascribed either to an intrinsically different SED or to absorption along our line of sight. As suggested by Brandt et al. (2001a) near-IR observations
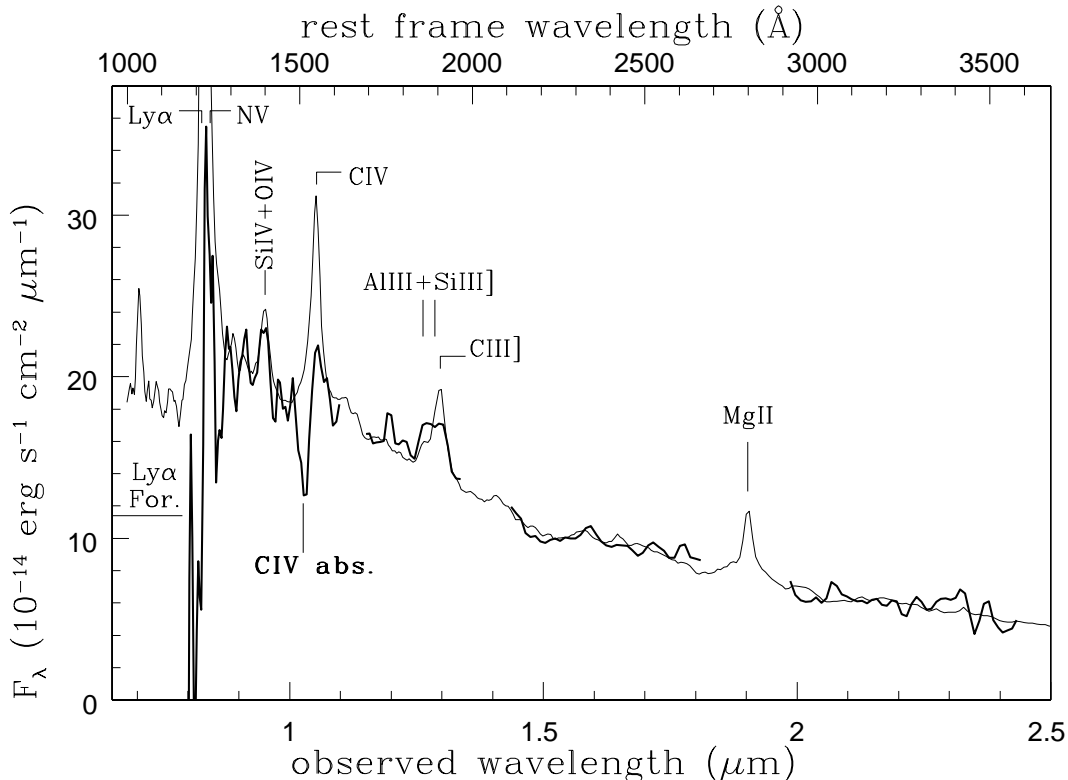
Figure 1. Thick line: observed spectrum of QSO SDSS 1044−0125. Thin line: template spectrum of (unabsorbed) optically selected QSOs (Francis et al. 1991) smoothed to the same resolution of our spectrum.

aimed at detecting resonant absorption lines in the rest-frame UV spectrum could tackle the issue.

In this letter we report new near-IR spectroscopic observations of this high redshift QSO which strongly support the scenario of heavy absorption due to gas along our line of sight.

2. Observations

The observations were obtained at the Italian Telescopio Nazionale Galileo, a 3.56m telescope, with the Near Infrared Camera Spectrograph (NICS), a cryogenic focal reducer designed as a near-infrared common-user instrument for that telescope. The instrument is equipped with a Rockwell 1024^2 HAWAII near infrared array detector. Among the many imaging and spectroscopic observing modes (Baffa et al. 2000), NICS offers a unique, high sensitivity, low resolution observing mode, which uses an Amici prims as a dispersing element (Oliva 2001). In this mode it is possible to obtain the spectrum from 0.8μm to $\sim2.5\mu$m in one shot. The spectral resolution with a $0.''75$ slit (as it was in our case) is ~75 and nearly constant over the whole wavelength range. Clearly, this observing mode is an optimal tool to study the near-infrared continuum of faint sources as well as for the detection of broad (~5000 km s^{-1}) emission and absorption lines in faint QSOs.

SDSSp J104433.04−012502.2 was observed on December 9th and 12th 2000. As mentioned above we used a $0.''75$ slit, whose width projected on the array

corresponds to three pixels, yielding a spectral resolution of 4500 km s^{-1}. Each of the two nights the object was observed for 30 minutes. Unfortunately, the presence of electronic noise during the second night prevented us to exploit the data at wavelength shortward of $\sim1.4\mu$m of this second section of observations, while at longer wavelengths we could combine the data of both nights. Wavelength calibration was performed by using an Argon lamp and the deep telluric absorption features. The telluric absorption was then removed by dividing the quasar spectrum by an A0 reference star spectrum observed at similr airmass. The intrisic features and slope of the reference star were then removed by multiplying the spectrum by the theoretical spectrum of A0 stars smoothed to our resolution.

3. Results and discussion

In Fig.1 we plot the resulting spectrum of SDSS 1044−0125 (thick line). The regions of bad atmospheric transmission are omitted. The signal-to-noise is about 25 in the H band, 15 in the J and K bands and 8 at 0.9μm. The increased noise at $\lambda < 0.95\mu$m is due to the drop of the detector sensitivity. However, both the Lyα and the sharp break blueward of the Lyα are real (Fan et al. 2000); the latter is due to the Lyα forest.

The thin line is the QSO template obtained by Francis et al. (1991) from a sample of optically selected QSOs, normalized to match the continuum of SDSS 1044−0125 and

smoothed to the same velocity resolution of our spectrum. It is quite impressive that the shape of SDSS 1044−0125 is essentially identical to the (lower redshift) template. Also, the spectral slope is $\alpha = -0.3$ ($F_\nu \propto \nu^\alpha$)[1] which is consistent with the median slope found by Francis et al. for their sample of QSOs. We will discuss these properties later on.
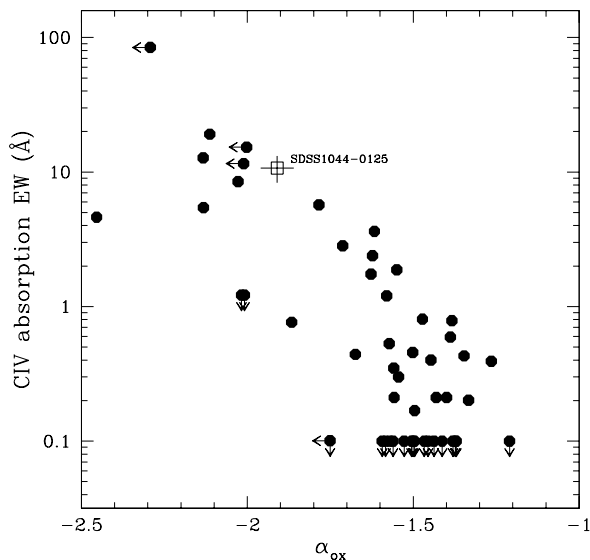

Figure 2. Equivalent width of the CIV absorption feature as a function of the optical–to–X-ray spectral index α_{ox} for a sample of QSOs (from Brandt et al. 2000). The location of SDSS 1044−0125 is identified with an hollow square.

Our spectrum shows evidence of the emission of Lyα+NV(1240Å), SiIV+OIV($\sim$1400Å), CIV (1549Å), and CIII] (1909Å) and possibly AlIII (1857Å) and SiIII] (1892Å). The MgII line at 2799Å lies in the bad atmospheric transmission region between H and K. Most interesting, we clearly detect a CIV absorption feature blueshifted with respect to the emission line, similarly to what observed in BAL QSOs or in other X-ray weak QSOs at lower redshift. The feature is marginally resolved: it has a width of $\sim$7600 km s^{-1} which implies an intrinsic width (deconvolved from the instrumental resolution) of $\sim$6100 km s^{-1}. The blue edge of the absorption feature extends to $\sim$12000 km s^{-1} from the CIV nominal wavelength. These values are not uncommon among BAL QSOs. The rest-frame equivalent width (EW) of the CIV absorption is 10.6±2.5Å.

Regardless of whether SDSS 1044−0125 is actually a BAL QSO or not, the detection of a deep CIV absorption feature strongly supports the scenario that the X-ray weakness is to ascribe to heavy obscuration along the line of sight. Indeed, as discussed in the introduction, Brandt et al. (2000) showed that CIV absorption is a powerful tool

to identify QSOs whose X-ray faintness is to ascribe to absorption by gas along the line of sight. In Fig.2 we show a revised version of Fig.4 in Brandt et al. (2000), where for a large sample of QSOs the EW of the CIV absorption line is reported as a function of the optical–to–X-ray spectral index α_{ox} (i.e. the X-ray fainter sources have more negative values of α_{ox}). The location of SDSS 1044-0125 on this diagram is marked with a hollow square and is in excellent agreement with the relation found for the low redshift QSOs, thus supporting that the X-ray weakness of this object is also due to gas absorption. As discussed in Brandt et al. (2001a), within the absorption scenario the lack of detection in the 2–7 keV band ($\sim$14–50 keV rest frame) implies that the column of absorbing gas is larger than $N_H > 10^{24}$cm^{-2}, i.e. this QSO is Compton thick.

If the absorbing was characterized by a Galactic dust–to–gas ratio and Galactic dust composition, then the optical extinction associated to the X-ray absorption should be $A_V > 500$ mag, which would completely obscure the QSO in the optical and in the UV. Instead, not only the QSOs is not optically absorbed, but it does not even appear to be reddened. We estimate the maximum reddening to be $E_{B-V} < 0.08$ mag [2]. Such a mismatch between dust and gas absorption was already noted previously in lower redshift objects (Maiolino et al. 2001a, Risaliti et al. 2001). In this respect BAL QSOs (along with some non-BAL QSOs) represent the extreme case of large gas absorption in the X-rays and little or no dust extinction/reddening in the optical-UV. Within this population of objects, SDSS 1044-0125 stands out as an even more extreme case. It is one of the BAL QSOs with the lowest reddening ever measured (Yamamoto & Vansevicius 1999) and the XMM measurement, along with the high redshift (which would shift a high energy photoelectric cutoff into the soft band), allows to set a lower limit on the absorbing column of gas which is the largest ever set for this class of objects. These values constrain the A_V/N_H of the gas along the line of sight to be less than 10^{-3} times the Galactic standard value. The extremely reduced value of A_V/N_H might either indicate that dust in the absorbing gas is absent or that it is mostly composed of large grains (which make the extinction curve flatter and reduce A_V/N_H, Maiolino et al. 2001b).

Although the CIV absorption and the X-ray absorption appear related, there is no clear indication that the two absorbing gaseous media are physically associated. However, as noted by Brandt et al. (2001b), if the X-ray absorbing gas has an $N_H > 10^{24}$cm^{-2} and it is outflowing with the terminal velocities inferred by the CIV absorption feature, this would imply a mass outflow larger than 5 M$_\odot$yr^{-1} and an outflow kinetic energy larger than

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[1] This is the slope in the range 1500–3500Å, in analogy with the range adopted by Francis et al. (1991), given that at shorter wavelengths various absorption systems affect the slope.

[2] The maximum reddening was estimated by assuming that the intrinsic slope was as high as α=1 (only $\sim$10% of the QSOs in the Francis et al. (1991) sample have a steeper slope, i.e. this is a deviation at about 2σ from the median slope) and then determining the E_{B-V} required to match the observed spectrum.

the ionizing luminosity emitted by the QSOs. Should such large and massive outflows result to be relatively common among high redshift QSOs, this would have important implications on the chemical enrichment of the intergalactic medium.

4. Conclusions

We have exploited a new low resolution near–infrared spectrometer to obtain the spectrum of the most distant known QSO, SDSS 1044−0125, over the whole 0.8–$2.5\mu m$ wavelength range, corresponding to $\sim$1170–3600Å rest frame. The spectrum reveals a prominent CIV blueshifted absorption feature, suggesting that most likely this is a Broad Absorption Line QSO. The large equivalent width of the CIV absorption feature (10.6Å) strongly supports that the X-ray weakness, recently identified by means of XMM observations of this QSO, is due to absorption by gas with $N_H > 10^{24} \mathrm{cm}^{-2}$.

The continuum of this QSO exactly matches the template of unabsorbed, optically selected QSOs, implying that no dust reddening is associated to the gas responsible for the X-ray absorption. We derive an upper limit to the (Galactic-like) reddening of $E_{B-V} < 0.08$ mag, which implies that the A_V/N_H of the gas along the line of sight is less than 10^{-3} of the Galactic value. The extremely reduced dust absorption and reddening is either due to an extremely reduced dust content or to dust mostly composed of large grains.

The inferred mass outflow is very high (5 $M_\odot \mathrm{yr}^{-1}$). If such large outflows are common among high redshift QSOs, these would have an important role in the chemical enrichment of the intergalactic medium.

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